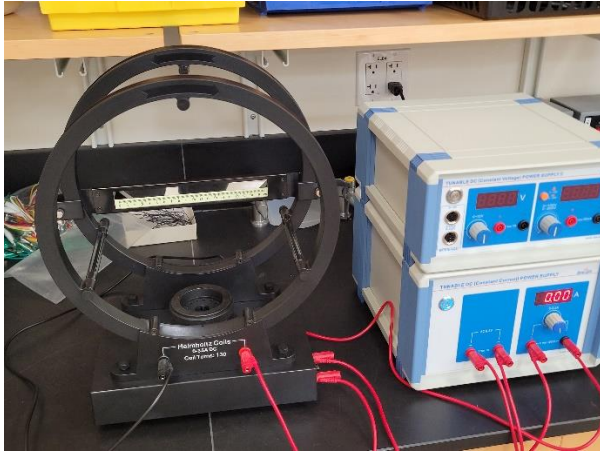


Physics 196 Lab 14: e/m Measurement

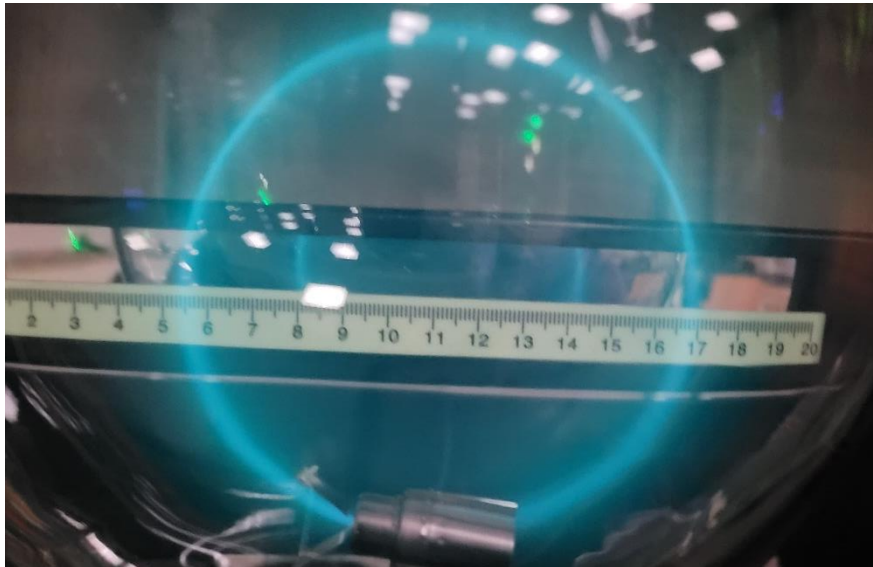
Equipment:

Lorentz Force Apparatus with Power Supplies
Magnetic Field Sensor with LabQuest Mini and Computer

Layouts:



Helmholtz coils without tube to measure magnetic field. Cyclotron orbit with power supplies, $V=200V$, $I= 1.5A$



Beam diameter can be measured by lining up beam with its reflection at position of ruler.

Summary:

Students will use a Lorentz Force Demonstrator Apparatus to measure the ratio of the electron's charge to its mass (e/m). An acceleration voltage V (upper right meter on apparatus and associated knob) accelerates electrons to a kinetic energy $eV = \frac{1}{2} mv^2$, from which the electron velocity can be determined: $v=(2eV/m)^{1/2}$. A magnetic field B perpendicular to the electron motion produced

in Helmholtz coils carrying current I (lower right meter on apparatus and associated knob) deflects the electrons into a circular path where the centripetal acceleration v^2/r is provided by the magnetic force evB . Setting $evB = mv^2/r$ gives $v=e r B/m$. Setting the two equations for velocity equal to each other, we find that

$$\frac{e}{m} = \frac{2V}{r^2 B^2}$$

By separately measuring B as a function of I , by recording V and I from the e/m apparatus, and by carefully measuring r (the radius of the electron beam path), it is possible to obtain a fairly accurate value for the ratio e/m . The electron beam path is visible (with the room lights turned off) because of ionizing collisions between the electrons and residual gas in the electron tube. The diameter of the path is obtained by carefully lining up the left and right ends of the observed circle, its reflection in a mirror, and a ruler set at the vertical midpoint.

Prelab:

A. Look up the value of the electron charge e , the electron mass m , and calculate the ratio e/m . Review and understand how the Lorentz Force Demonstrator allows for the measurement of e/m .

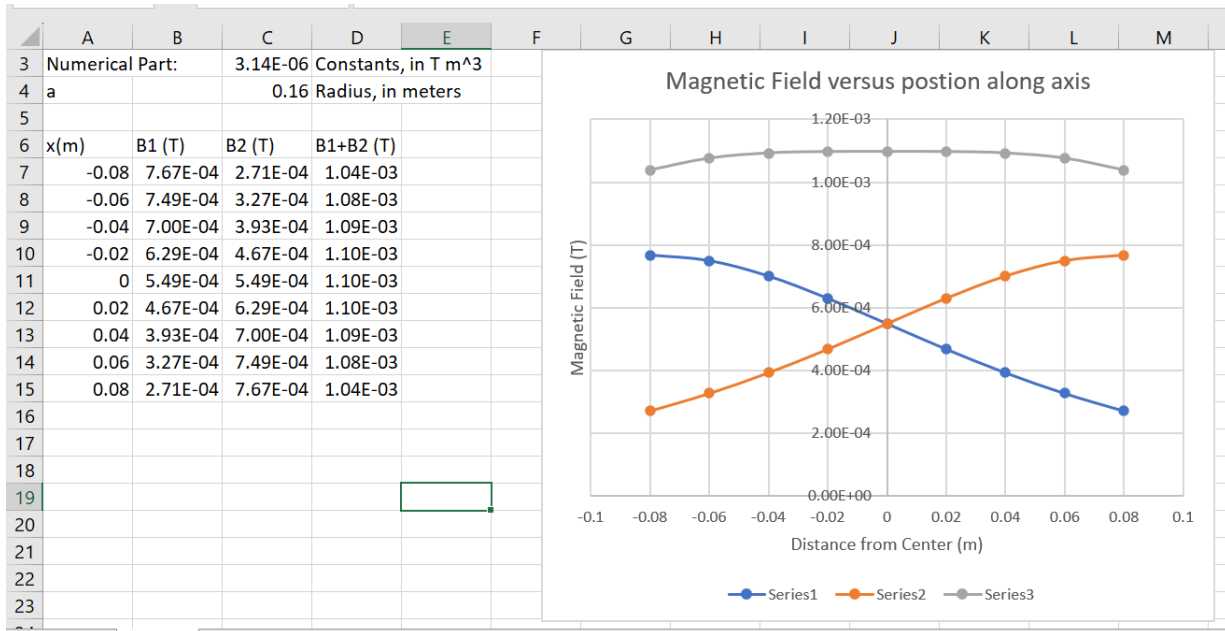
B. The Helmholtz coils have a mean diameter of 320 mm, a coil separation of 160 mm, and there are 130 turns per coil. They are designed to provide a very uniform magnetic field over the measurement volume. In class we learned that the magnitude of the magnetic field along the x -axis from a circular loop with N turns of wire of radius a lying in the y - z plane and centered at the origin is

$$B = \frac{N\mu_0 I a^2}{2(x^2 + a^2)^{3/2}}$$

In this formula, $x=0$ at the location of the coil. If we do a coordinate transformation so that $x=0$ at a distance 0.08 m to the right of the left coil (Coil 1, B_1) and 0.08 m to the left of the right coil (Coil 2, B_2) we can calculate the field of each coil separately and sum them:

$$B_1 = \frac{N\mu_0 I a^2}{2((x+.08m)^2 + a^2)^{3/2}} \quad B_2 = \frac{N\mu_0 I a^2}{2((x-.08m)^2 + a^2)^{3/2}} \quad B_{tot} = B_1 + B_2$$

Where $\mu_0 = 4\pi \times 10^{-7} \text{ Tm/A}$. Below I have tabulated and plotted on the same graph the calculated magnetic fields B_1 , B_2 and B_{tot} for a current of 1.5A, $N=130$, and $a=0.16\text{m}$ for x values ranging from -0.08 m to $+0.08\text{ m}$ at 0.02 m intervals (9 points). Discuss how the spacing of the two coils leads to a uniform magnetic field along the axis. In the first part of the lab we will measure the magnetic field in the radial direction half way between the two coils, and find that it is also surprisingly uniform. (It may be a little different than the value calculated below, and we will use the measured value at different currents for our experiment).



Lab:

In your lab notebook, please include a description and labelled diagram of each part of the experiment, a data table, graphs as appropriate, and a discussion of the results including comparisons between data and expected results and a conclusion.

Experiment Part A, Magnetic Field Calibration: As a class, calibrate the magnetic field half way between the Helmholtz coils. (Use an apparatus for which the instructor has removed the spherical tube). Divide into 5 teams. Each team will measure the field at a different current to the coils. The whole class will use the same data. Adjust the ruler at the back of the apparatus so that if the magnetic field sensor is lined up with it horizontally, it will be at the vertical midpoint of the coils. Use the magnetic field sensor, the LabQuest mini and the laptop to measure the field at different locations and currents. Hold the sensor so that the tip is parallel to the axis between the coils, and half way between them. Figure out the center position of the Helmholtz coils on the ruler. Depending on the team, turn up the magnet current (as accurately as you can read it) to either 1.00 A (Team 1), 1.25 A (Team 2), 1.50 A (Team 3), 1.75 A (Team 4) or 2.00 A (Team 5). Measure the magnetic field half way between the coils (in depth away from you) at transverse positions of center, center +/- 3 cm, center +/- 6 cm and center +/- 9 cm. Record as a class and move to the next team. Remember to zero the magnetic field sensor once at each current by turning the current to 0A. We will assume that the magnetic field vs. current reading will be the same for all of the Lorentz Force Demonstrators. (This may be a source of systematic error).

Measured Magnetic Field for transverse position ► Current ▼	-9 cm	-6 cm	-3 cm	0 cm	3 cm	6 cm	9 cm
Team 1: 1.00 A							
Team 2: 1.25 A							
Team 3: 1.50 A							
Team 4: 1.75 A							
Team 5: 2.00 A							

Discuss the observed uniformity as a function of radial position. Graph the magnetic field at the center position vs. current. Is the magnetic field proportional to current? Compare the measured value at 1.5A to what was calculated in the prelab.

Experiment Part B, Electron Beam Radius vs. V and I, and calculation of e/m: Each team should now go to its complete apparatus (with an electron beam tube) and turn on the power switch, with all other voltages and currents turned off (knobs counterclockwise). We will allow the systems to warm up for 5 minutes, and then turn off the room lights. Prepare a table in your lab notebook with ten rows and with columns which will allow you to record the electron accelerating voltage, the magnet current, the position of the left end of the electron beam circle, the position of the right end of the electron beam circle, the calculated circle radius, the magnetic field value and the calculated value of e/m. The rows will include measurements with the accelerating voltage set at 150V and 200V, and at the 5 magnet currents used in Part A. When the apparatus is warmed up and the lights are turned out, turn the accelerating voltage to 150V and the magnet current to 1.00 A. Make sure the tube is rotated in its socket so that the electron beam makes a circle instead of a spiral. Leave the ruler horizontal, and translate its position vertically so it is centered in height on the electron beam circle. With one eye covered, and your other eye a fair distance away from the apparatus, move your head left or right so that the electron beam and the reflection of the electron beam are lined up, and record the ruler reading you observe the beam(s) at. (Do this for the left arc of the circle and the right arc of the circle, and record in your lab notebook on the appropriate row. If the electron beam glow is a bit blurred out, try to make the measurement at the center of the blur.). Now repeat the measurements for the other magnet currents, and then the other accelerating voltage. Make sure that all lab partners take turns making measurements.

When you are finished with the measurements, insert the values of the central magnetic field from Part A appropriate to the magnet current. Calculate the radius of the electron beam circle, and then calculate the measured value of e/m for each row. Take the mean of the e/m measurements, and approximate the statistical error based on the range of your measurements. Compare to the theoretical value of e/m calculated in the prelab. Is it close to your measured value? What kind of systematic errors can you think of which might affect the result? Compare your results to those of other teams.